

PROCESS FOR ACTIVATING A CATALYST CONTAINING AN S-
CONTAINING ADDITIVE

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CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority from European Patent Application Serial No. 00201294.6, filed on April 11, 2000 and U.S. Provisional Patent Application Serial No. 60/199,768, filed April 26, 2000.

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BACKGROUND OF THE INVENTION

Field of the invention

The present invention relates to a process for activating catalysts containing an S (sulfur)-containing organic additive, in particular a hydrotreating catalyst containing an S-containing organic additive.

Prior Art

Hydrotreating catalysts comprise hydrogenation metal components, generally a Group VI metal component such as molybdenum and/or tungsten and a Group VIII metal component, such as nickel and/or cobalt generally on an oxidic carrier. Hydrotreating catalysts containing S-containing organic additives are known in the art.

For example, European patent application 0 300 629 and European patent application No. 0 357 295 describe hydrotreating catalysts comprising a support impregnated with at least one member of molybdenum, tungsten, and/or Group VIII of the Periodic Table, and a mercapto-compound selected from mercaptocarboxylic acids, amino-substituted mercaptanes, di-
30 mercaptanes, and thioacids.

European patent application No. 0 506 206 also describes a hydrotreating catalyst comprising an S-containing additive selected from the group of bi-mercaptanes, aminosubstituted mercaptanes, and thiocarboxylic acids. Some of the catalysts described in this reference are activated by a 5 treatment with hydrogen at a temperature from room temperature up to 400°C. Similar subject-matter is described in European patent application No. 0 338 788, and European patent application No. 0 289 211.

US 4,636,487 describes a hydrotreating catalyst comprising a support 10 and a hydroxymercaptide of one or more metals, which may be the reaction product of a mercaptoalcohol and one or more metal compounds. The catalyst may be activated with hydrogen at a temperature of 66-316°C.

US 5,139,990 describes a hydrotreating catalyst comprising a carrier and 15 hydrogenation metal components which is treated with an aqueous medium comprising a water-soluble or water-miscible S-containing organic additive, followed by drying the resulting catalyst and activating it with hydrogen at a temperature of 100-600°C.

20 European patent application No. 0 496 592 describes a hydrotreating catalyst comprising a carboxylic acid and an organic sulfur compound which may be a mercaptocarboxylic acid.

WO 94/25157 is directed to a process for treating spontaneously 25 combustible catalysts. It describes a process in which a catalyst is contacted with elemental sulfur and an oxygen-containing additive having at least 12 carbon atoms. The oxygen-containing additive is used to decrease the self-heating properties of the catalyst and improve sulfur retention.

30 As indicated above, many of the catalysts containing an S-containing organic additive are activated by being contacted with hydrogen. It has now been found that the activity of these catalysts can be increased if the catalyst is

contacted with an organic liquid either prior to or simultaneous with the contacting with hydrogen.

Accordingly, in one embodiment, the present invention pertains to a 5 process for activating a catalyst composition comprising at least one hydrogenation metal component of Group VI or Group VIII of the Periodic Table, and an S-containing organic additive, wherein the catalyst is contacted with hydrogen at a temperature between room temperature and about 600°C, and prior to or during the contacting with hydrogen the catalyst is contacted with an 10 organic liquid.

In a second embodiment, our invention is a catalyst obtained by the above process.

15 In a third embodiment, our invention is a process for hydrotreating a hydrocarbon feed by contacting the feed with the above catalyst at hydrotreating conditions.

Other embodiments of our invention encompass details about reactant 20 compositions, process steps and conditions, etc., all of which are hereinafter disclosed in the following discussion of each of the facets of our invention.

DETAILED DESCRIPTION OF THE INVENTION

25 The addition of the organic liquid

In the process according to our invention, an additive-containing catalyst is contacted with an organic liquid either prior to or during the hydrogen treatment. To achieve a more controllable process it is preferred for the organic liquid to be added in the absence of hydrogen prior to the hydrogen treatment.

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The organic liquid generally has a boiling range of about 100-550°C, preferably about 150-500°C. It generally is a petroleum fraction. By their nature,

petroleum fractions comprise less than about 12 wt.% of oxygen. Petroleum fractions comprising less than about 8 wt.% of oxygen, preferably less than about 5 wt.%, more preferably less than about 2 wt.%, specifically less than about 0.5 wt.% of oxygen, may be preferred. Although the olefin content of the

5 organic liquid is not critical to the process according to the invention, petroleum fractions with an iodine number of about 50 or less, specifically about 30 or less, may be preferred. Examples of suitable petroleum fractions include fractions comprising heavy oils, lubricating oil fractions like mineral lube oil ($360^{\circ}\text{C} < \text{BP} < 500^{\circ}\text{C}$), atmospheric gas oils, vacuum gas oils, straight run gas

10 oils ($250^{\circ}\text{C} < \text{BP} < 350^{\circ}\text{C}$), white spirit ($180^{\circ}\text{C} < \text{BP} < 220^{\circ}\text{C}$), middle distillates like diesel, jet fuel and heating oil, naphthas, and gasoline. Preferably white oil, gasoline, diesel, gas oil, or mineral lube oil is used.

The organic liquid appears to ensure that the catalyst is able to withstand

15 the conditions prevailing during the hydrogen treatment, that is, during the contacting of the catalyst with hydrogen. The organic liquid is not particularly intended to bring sulfur into the catalyst, since the catalyst already contains sulfur in the form of the sulfur-containing additive. Nevertheless, petroleum cuts such as a gas oil or diesel may sometimes contain sulfur. Generally, the organic

20 liquid will contain less than 10 wt.% of sulfur, preferably less than 5 wt.%. The amount of sulfur added with the organic liquid will be less than 40%, preferably less than 35% of the total amount of sulfur added to the catalyst with the organic liquid and by way of the sulfur-containing additive already present on the catalyst.

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The amount of organic liquid generally is about 20-500% of the catalyst pore volume which can be filled with the liquid at issue under the conditions of application of the liquid. The pore volume can easily be determined by slowly adding liquid under said conditions to a certain amount of catalyst in a closed

30 flask while shaking and determining by visual inspection when the liquid is no longer adsorbed. Another method is to add excess liquid and to remove the excess from the catalyst, e.g., by centrifugation. The person skilled in the art of

pore volume impregnation is familiar with these procedures. To get the desired effect and avoid waste of material an amount of about 50-200%, more in particular about 50-125% of the catalyst pore volume, is preferred. Evidently, if excess liquid is present it can easily be removed, e.g., by drying the catalyst.

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The way in which the catalyst is contacted with the organic liquid is not critical to the invention as long as it is ensured that each catalyst particle is contacted with the organic liquid. Conventional mixing methods may be applied. The organic liquid is generally contacted with the catalyst particles at a 10 temperature between room temperature and about 200°C. Increased temperatures may sometimes be desired because they decrease the viscosity of the liquid. The suitable contacting time may depend on whether the operation is carried out *ex situ* or *in situ*. For *ex situ* operation the temperature may preferably be between room temperature and about 75°C. For *in situ* operation 15 the temperature may preferably be between about 100 and about 175°C.

Either simultaneous with or after the incorporation of the organic liquid, the catalyst is contacted with hydrogen at a temperature between room temperature and about 600°C, preferably between about 100 and about 450°C, 20 more preferably between about 200 and about 400°C. The hydrogen treatment is not intended to introduce sulfur into the catalyst. Nevertheless, some S-containing compound, in particular some H₂S, may be present in the hydrogen. It is intended to introduce less than about 10% of the stoichiometric sulfur quantity necessary to convert the hydrogenation metals into Co₉S₈, MoS₂, WS₂, 25 and Ni₃S₂, respectively, into the catalyst by way of S-containing compound added to the hydrogen, preferably less than about 5%, more preferably in the substantial absence of S-containing compound added to the hydrogen. It is noted that the phrase "S-containing compound added to the hydrogen" is intended to refer to S-containing compound added extraneously to the 30 hydrogen. It does not include S-containing compound, in particular H₂S generated by decomposition of the S-containing organic additive. Recycle of the hydrogen gas may be an attractive option.

The total amount of sulfur-containing compound which is incorporated into the catalyst in the process according to the invention, including the amount of sulfur added by way of the S-containing organic additive and the amount of 5 sulfur added with the organic liquid, if any, is generally selected to correspond to about 50-300%, preferably about 70-200%, more preferably about 80-150%, of the stoichiometric sulfur quantity necessary to convert the hydrogenation metals into Co_9S_8 , MoS_2 , WS_2 , and Ni_3S_2 , respectively.

10 The total pressure during the process according to the invention, more in particular, the pressure during the hydrogen activation step, is not critical. It will generally be between atmospheric pressure and about 300 bar, depending on where the process is carried out. If the process, in particular the hydrogen activation step is carried out *ex situ*, the pressure may, e.g., be between 15 atmospheric pressure and about 10 bar. When the hydrogen treatment is carried out *in situ*, the pressure may be much higher, e.g., in the range of about 25 to about 300 bar.

The contacting in the gaseous phase with hydrogen can be carried out in 20 any suitable manner, including in fixed bed processes and moving bed processes. Since, depending on the nature of the S-containing organic additive, the activation of the catalyst with hydrogen may be exothermic by nature, it may be important that the temperature of the catalyst is well-controlled. Generally, such control is easier in a moving bed process. In the context of the present 25 specification, a moving bed process is intended to encompass all processes in which the catalyst moves relative to the reactor. Examples are ebullated bed processes and processes carried out in a rotary furnace. In the latter case, the contacting can be done either co-currently or counter-currently, with counter-current operation being preferred.

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The various steps of the process according to the invention can be carried out *ex situ* or *in situ*. In the context of the present specification, the term

in situ means in the reactor in which the catalyst will eventually be applied to effect hydrotreating. Conversely, *ex situ* means outside said reactor.

For example, it is possible to effect the contacting with the organic liquid 5 *ex situ* while the contacting with hydrogen is effected *in situ*. It is also possible to effect the complete process *ex situ*, or to effect the complete process *in situ*. It is generally preferred to carry out the complete process *ex situ*, because this generates less downtime for the hydrotreating reactor and simplifies the reactor start-up.

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If the complete process according to the invention is carried out *ex situ*, it may be desirable to passivate the activated catalyst prepared in this way, since the resulting catalyst is self-heating. Passivation can be done by contacting the catalyst with an oxygen-containing compound under controlled conditions. The 15 use of an oxygen-containing gas, such as air, is a well-known embodiment. Alternatively, the catalyst may be passivated by being contacted with an organic liquid, such as diesel, gas oil, white spirit, or lube oil. Passivation processes are known in the art. See, for example, EP-897 748 and NL 8900914, which describe the use of hydrocarbons, and V.M. Browne, S.P.A. Louwers, and R. 20 Prins, Catalysis Today volume 10 number 3 pp 345-52 (1991) and S.P.A. Louwers, M.W.J. Craje, C. Geantet, A.M. van der Kraan, and R. Prins, Journal of Catalysis volume 144 number 2 pp. 579-96 (1993), both of which describe the use of oxygen.

25 The additive-containing catalyst

In principle, the additive-containing catalyst can be any catalyst which comprises a Group VIB hydrogenation metal component and/or a Group VIII hydrogenation metal component, and an S-containing organic additive, generally on a carrier. Catalysts comprising the combination of a Group VIB 30 hydrogenation metal component and a Group VIII hydrogenation metal component are preferred. As the skilled person will recognise, the metals may be present in any form. When they are incorporated into the catalyst

composition they are often in the form of their salts or oxides. After calcination they are converted partly or wholly into their respective oxides. After sulfidation and during use the metals are at least partly present in the sulfidic form.

5 As Group VIB metals may be mentioned molybdenum, tungsten, and chromium. Group VIII metals include nickel, cobalt, and iron. Catalysts comprising molybdenum and/or tungsten as Group VIB metal component and nickel and/or cobalt as Group VIII metal component are the most common. The catalyst usually has a metal content in the range of about 0.1 to about 50 wt.%
10 calculated as oxides on the dry weight of the catalyst not containing the additive. The Group VIB metal will frequently be present in an amount of about 5-40 wt.%, preferably about 15-30 wt.%, calculated as trioxide. The Group VIII metal will frequently be present in an amount of about 1- 10 wt.%, preferably about 2-7 wt.%, calculated as monoxide. The catalyst may also contain other
15 components, such as phosphorus, halogens, and boron. Particularly, the presence of phosphorus in an amount of about 1-10 wt.%, calculated as P_2O_5 , may be preferred.

The catalyst carrier which is generally present may comprise the
20 conventional oxides, e.g., alumina, silica, silica-alumina, alumina with silica-alumina dispersed therein, silica-coated alumina, magnesia, zirconia, boria, and titania, as well as mixtures of these oxides. As a rule, preference is given to the carrier comprising alumina, silica-alumina, alumina with silica-alumina dispersed therein, or silica-coated alumina. Special preference is given to the carrier
25 consisting essentially of alumina or alumina containing up to about 25 wt.% of other components, preferably silica. A carrier comprising a transition alumina, for example an eta, theta, or gamma alumina is preferred within this group, with a gamma-alumina carrier being especially preferred. Additionally, although at present less preferred, the catalyst may contain 0- about 60 wt.% of zeolite.
30 The catalyst's pore volume (measured via N_2 adsorption) generally is in the range of about 0.25 to about 1 ml/g. The specific surface area will generally be in the range of about 50 to about 400 m^2/g (measured using the BET method).

Generally, the catalyst will have a median pore diameter in the range of about 7-20 nm, as determined by N₂ adsorption. The figures for the pore size distribution and the surface area given above are determined after calcination of the catalyst at about 500°C for one hour.

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The catalyst is suitably in the form of spheres, pellets, beads, or extrudates. Examples of suitable types of extrudates have been disclosed in the literature (see, int. al., US 4,028,227). Highly suitable are cylindrical particles (which may be hollow or not) as well as symmetrical and asymmetrical 10 polylobed particles (2, 3 or 4 lobes).

The additive present in the catalyst may be any S-containing organic additive. In the context of the present specification the term organic refers to an additive comprising at least one carbon atom and at least one hydrogen atom.

15 Preferred compounds include organic compounds having at least one mercapto-group. Within the group of mercapto-compounds, mercaptocarboxylic acids represented by the general formula HS-R1-COOR, wherein R1 stands for a divalent hydrocarbon group with 1- about 10 carbon atoms and R stands for a hydrogen atom, an alkali metal, an alkaline earth metal, ammonium, or a linear 20 or branched alkylgroup having 1 to about 10 carbon atoms. Examples include mercaptoacetic acid (HS-CH₂-COOH), beta-mercaptopropionic acid (HS-CH₂CH₂-COOH), methylmercaptoacetate (HS-CH₂-COOCH₃), ethyl 2-mercptoacetate (HS-CH₂-COOC₂H₅), ethylhexyl mercaptoacetate (HS-CH₂-COOC₈H₁₇), and methyl 3-mercaptopropionate ((HS-CH₂CH₂-COOCH₃).

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Further compounds preferred within the group of mercapto-compounds include aminosubstituted mercaptanes represented by the general formula H₂N-R₂-SH, wherein R₂ stands for a divalent hydrocarbon group having 1- about 15 carbon atoms. Examples of these compounds include 2-amino 30 ethanethiol (H₂N-CH₂CH₂-SH), and 4-amino thiophenol (H₂N-C₆H₄-SH).

Additional compounds within the group of mercapto-compounds are the di-mercaptanes represented by the general formula HS-R₃-SH, wherein R₃

stands for a divalent hydrocarbon group having 1- about 15 carbon atoms. Examples of these compounds include ethanedithiol (HS-CH₂CH₂-SH) and 1,4-butanedithiol (HS-(CH₂)₄-SH).

5 Preferred compounds also include thioacids of the formula R₄-COSH, wherein R₄ stands for a monovalent hydrocarbon group having 1- about 15 carbon atoms. Examples of these compounds include thioacetic acid (CH₃-COSH) and thiobenzoic acid (C₆H₅COSH). Dithioacids of the formula HSOC-R₅-COSH, wherein R₅ is a divalent hydrocarbon group with 1- about 15 carbon
10 atoms may also be suitable. An example is dithio adipic acid (HSOC-C₄H₁₀-COSH).

Preferred compounds also include mercaptoalcohols of the general formula R₆S-R₅-(OH)_n, wherein R₅ represents an alkyl group having from 1 to
15 about 15 carbon atoms or a phenyl group, R₆ represents a hydrogen atom or an alkyl group having 1 or 2 carbon atoms, and n is 1 or 2. Examples of these compounds include 2-mercptoethanol, 2-(methylthio)ethanol, 2-(ethylthio)ethanol, 3-mercpto-2-butanol, 4-mercaptophenol, 2-(methylthio)phenol, 4-(methylthio)phenol, 2-(ethylthio)phenol, 3-mercpto-1,2,-
20 propanediol, 3-methylthio-1,2, propanediol, and 3-ethylthio-1,2, propanediol. Other suitable compounds include sulphoxides of the formula R₇-SO-R₈, wherein R₇ and R₈ are hydrocarbon groups with 1- about 5 carbon atoms. An example is dimethyl sulfoxide (CH₃-SO-CH₃).

25 Ammonium thiocyanate and thiourea may also be useful compounds, as may be the various dithiocarbamic acids and the salts thereof, such as ethylene bisdithiocarbamic acid and its salts, and dimethyl dithiocarbamic acid and its salts. Other suitable compounds include mercaptodiathiazoles and their salts, such as 2,5-dimercpto-1,3,4,-diathiazoles and its salts.

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Other compounds which may be useful are polysulphides of the formula R₉-S_x-R₁₀, wherein x is a value of 1- about 15 and R₉ and R₁₀ are alkyl

groups, preferably branched alkyl groups, with 1- about 30 carbon atoms. Related compounds are those with the formula HO-R11-Sx-R12-OH, wherein x is a value of 1-15 and R11 and R12 are alkyl groups with 1- about 8 carbon atoms.

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At this point in time the mercapto-compounds, in particular the mercaptocarboxylic acids are considered preferred for reasons of catalyst activity. Other compounds, in particularly those which are soluble in or miscible with water may be preferred for environmental reasons (less smell and no 10 organic solvent being necessary).

A single compound as well as a combination of compounds may be used as additive.

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The amount of additive present in the additive-containing catalyst depends on the specific situation. It was found that the appropriate amount of additive generally lies in the range of about 0.01-2.5 moles of additive per mole of hydrogenation metals present in the catalyst. If the amount of additive added is too low, the advantageous effect associated with its presence will not be obtained. On the other hand, the presence of an exceptionally large amount of additive will not improve its effect. Generally it is intended that the amount of sulfur incorporated into the catalyst by way of the additive is selected to correspond to about 5-200%, preferably about 50-200%, more preferably about 20 80-150%, of the stoichiometric sulfur quantity necessary to convert the 25 hydrogenation metals into Co_9S_8 , MoS_2 , WS_2 , and Ni_3S_2 , respectively.

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The way in which the additive is incorporated into the catalyst composition is not critical to the process according to the invention. The additive may be incorporated into the catalyst composition prior to, subsequent to, or simultaneously with the incorporation of the hydrogenation metal components. For example, the additive can be incorporated into the catalyst composition prior to the hydrogenation metal components by being added to the carrier

before the hydrogenation metal components are. This can be done by mixing the additive with the carrier material before it is shaped, or by impregnating the shaped carrier material with the additive. This embodiment is not preferred at this point in time.

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Alternatively, the additive can be incorporated into the catalyst composition simultaneously with the hydrogenation metal components. This can be done, e.g., by mixing the additive and the hydrogenation metal components with the carrier material before shaping or by impregnating the carrier with an 10 impregnation solution comprising the hydrogenation metal components and the additive, followed by drying under such conditions that at least part of the additive is maintained in the catalyst.

It is also possible to incorporate the additive into the catalyst composition 15 subsequent to the hydrogenation metal components. This can be done, e.g., by first incorporating the hydrogenation metal components into the catalyst composition, e.g., by mixing them with the carrier material or by impregnating the carrier with them, optionally followed by drying and/or calcining, and subsequently incorporating the additive, e.g., by impregnation, optionally 20 followed by drying under such conditions that at least part of the additive is maintained in the catalyst.

Depending on the nature of the additive and the way in which it is incorporated into the catalyst composition, the additive may be used in solid 25 form, in liquid form, or dissolved in a suitable solvent. It may be preferred for the additive to be incorporated into the catalyst dissolved in water.

Use of the activated catalyst prepared according to the invention

30 The catalyst activated by the process according to the invention can be used in the hydrotreating of hydrocarbon feeds. The hydrotreating generally takes place under conventional hydrotreating conditions, such as temperatures

in the range of about 250-450°C, pressures in the range of about 5-250 bar, space velocities in the range of about 0,1-10 h⁻¹, and H₂/oil ratios in the range of about 50-2000 Ni/l. Examples of suitable feeds include middle distillates, kerosine, naphtha, vacuum gas oils, heavy gas oils and residues. Preferably, 5 the hydrocarbon feed contains at least about 0.2 wt% of sulfur, calculated as atomic sulfur S. Examples of suitable hydrotreating reactions are (deep) hydrodesulfurisation, hydrodenitrogenation, hydrodearomatisation, and hydrodemetallisation. (Deep) hydrodesulfurisation, hydrodenitrogenation, and hydrodearomatisation are preferred.

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Example 1

Starting material

A conventional hydrotreating catalyst containing 24 wt.% molybdenum, calculated as trioxide, 4 wt.% nickel, calculated as oxide, and 7 wt.% 15 phosphorus, calculated as P₂O₅, on a gamma-alumina carrier was impregnated by pore volume impregnation with a solution of HS-CH₂-COOH in water, containing 1 mole HS-CH₂-COOH per mole of the total of molybdenum and nickel. Then, the catalyst is dried rotating in hot air to a product temperature of about 100°C.

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Comparative activation procedure

The additive-containing starting catalyst (10 ml) was activated at atmospheric pressure with H₂ (flow = 5 l/hr). The temperature was increased by 0.5°C per minute to 300°C and held at that temperature for 3 hours.

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Activation procedure according to the invention

The additive-containing starting catalyst was pore volume impregnated with SRGO (straight run gas oil) in an amount corresponding to 0.046 g SRGO per gram catalyst. This additive-containing SRGO-impregnated Ni-Mo-P/γ-Al₂O₃ 30 catalyst (10 ml) was activated in the same way as described above.

Testing

The catalysts were tested in an upflow tubular reactor using a SRGO with the properties given in table 1. The reaction conditions are given in table 2.

Table 1: feedstock properties

| Type feed | Straight run gas oil |
|--------------------------------|----------------------|
| Nitrogen (ASTM D-4629) (ppmwt) | 115 |
| Sulfur (ASTM D-4294) (wt.%) | 1.2 |
| Density 15°C (g/ml) | 0.84 |
| Dist. (°C) (ASTM D 1160) | |
| IBP | 121 |
| 5 vol. % | 177 |
| 10 vol. % | 203 |
| 30 vol. % | 254 |
| 50 vol. % | 292 |
| 70 vol. % | 330 |
| 90 vol. % | 386 |
| 95 vol. % | 412 |
| FBP | 476 |

5 Table 2: Reaction conditions

| | |
|----------------------------|-----|
| Temperature (°C) | 340 |
| Pressure (bar) | 30 |
| H ₂ /oil (NI/I) | 250 |
| LHSV (h-1) | 1.0 |

The oil product from the reactor was analysed, and the relative volume activities of the catalysts for hydrodesulfurisation, hydrodenitrogenation, and 10 hydrodearomatisation were calculated, with the activity of the starting material activated using the comparative activation procedure being set at 100. The results are given in Table 3 below.

Table 3: test results

| | Comparative activation procedure | Activation procedure according to the invention |
|---------|----------------------------------|---|
| RVA HDS | 100 | 116 |
| RVA HDN | 100 | 104 |
| RVA HDA | 100 | 110 |

This shows that the activation procedure according to the invention, which includes a catalyst prewetting step, shows an improved activity as compared to the comparative activation procedure.